Chapter 1

Introduction

1.1 Inventory

Inventories are referred as most strategic position in the structure of working capital for many business industries. It is quite natural that inventory helps to maximize profit/minimize total cost. Inventory is defined as stock of physical products those applied to satisfy consumer requirements and are stored in different forms by an organization for packing, processing, transformation, use or sale in a future production of time. By using the data of inventory records, business organization obtains a sense of when to order new goods. When one can exactly know what inventory he has and where it is stored, then he can recover it and fulfill customer orders. The capability of a company to conduct customer inquiries and satisfy their orders shows higher profit. In case, if some customers have to wait for company's responses or goods then they may take away their orders and move on to other companies. Inventory plays important items of current assets which provides smooth operation during production process for a company.

Some basic types of inventory are as follows:

(i) **Raw materials** purchased products or extracted items made into components or products.

(ii) **Components** parts utilized to make final item.

(iii) **Work-in-process** items in process throughout the plant.

(iv) **Finished goods** products sold to customers.

(v) **Distribution inventory** finished goods in the distribution system.

Inventory of materials reaches about at several stages and departments of an organization. A production department holds inventory of raw materials for manufacturing operation. On the other hand, inventory of semi-finished items at different stages are stored for further procedure. Finished or completed items inventory are transferred to distinct distribution centers, shopping malls. Completed or finished items inventory is stored by the organization at several dealers and holds there until it sent to market and end consumers. In addition, organizations also stored raw materials, defective items, and scrap goods for service segment. Likewise, it also incorporates supportive materials which helps to continue manufacturing process.

There are several reasons for holding inventory:

(i) **To fulfill unexpected demands** Business sector knows that customers await for items and services when they required. For this reason, business sector generally holds inventories to satisfy these unexpected demands. These demands may shows congestion of inventories as it is quite unexpected that when customers would move to buy the items.

(ii) **To run smooth business of seasonal demands** For upcoming important events and the changing seasons, almost all business organization stored inventories for fulfilling those seasonal demands to customers. For example, Diwali/Dipabali festival is one of the most upcoming events. Along with the coming event, all crackers manufacturing companies are busy satisfying the upcoming Diwali/Dipabali demands of customers. In case, if manufacturing company does not have any inventory, then how can they fulfill these seasonal demands.

(iii) **To receive a chance of quantity discounts** In business sector, it is observed that whenever any customer purchase bulk size of inventories from any suppliers or any manufacturing companies, customer can receive some quantity discounts on that purchase. Generally, these suppliers or any manufacturing companies give such discount policy to draw an attention and maintain their customers.

(iv) **To protect against shortage** Business sector stores large number of inventories for avoiding shortage. On the other hand, by displaying these bulk size of inventories they can attract customers. Usually customers are more attractive when there are large amount of products in a shop.

Along with the necessity of holding inventories, business sector must be aware with the fact that there are some major risks of excessive inventories which are given below:

a. For some products, the holding area would have to be safe, clean, dirt-free. This additional holding cost can enhance the total cost.

b. The increase in the size of inventories shows that rest cost for inventories i.e., shortage cost, labor cost, and inspection cost are also grows.

Some disadvantages of inventory are:

(a) If ordering, setup costs are high, then total cost is also inclined.

(b) Higher holding or carrying cost also increases warehouse lease, insurance.

(c) Some costs for labor remuneration have to consider.

(d) Difficult to manage uncertainty of customers demand and lead time.

1.2 Literature overview about inventory

Throughout the world, India is one of the countries, who first commenced the application of Operations Research. Initially, O.R. (Operations Research) developed at the time of World War II in England. In the term O.R. (Operations Research), the word 'Operations' originated from the huge utilizations of O.R. to military operations. Military resources was very limited at that time. Mainly, O.R. applications was very helpful to obtain the most effective usage of military resources. After the war, the application of O.R. distributed in several countries like UK and USA. With the applications of O.R. lots of scientists understood that they can apply those principles for solving various troubles in the government departments, business management.

The EOQ formula, which is initially formulated by Harris in 1913, is discussed by R.H. Wilson in 1934. During the time-period 1925 to 1926, the Western Electric Company discovered some techniques related for sampling of quality control, which is applied to manage attributes of raw materials, completed/finished products.

In 1949, first Operations Research unit (Regional Research Laboratory) is established in Hyderabad, India. Later, Operations Research unit is developed in Indian Statistical Institute, Calcutta for National Planning and Survey in 1953. The first members of International Federation of Operations Research societies named as Operations Research Society of India was buildup in 1955. In present days, O.R. is a famous subject in management institutes and schools of mathematics.

O.R. (Operations Research) is utilized in most of the fields. It can be stated that O.R. is constructed from many subjects such as mathematics, statistics, engineering. Some remarkable techniques used in O.R. are linear and non-linear programming, distance related network techniques, project management, dynamic programming, inventory control, inventory management, integer programming, game theory, goal programming, markov process, queuing theory, simulation.

An operations research model is classified as real-life system. By using those models, one can clearly determined some facts like how to plan the movement of products in a factory, predicting the demand of products by using a linear equation. Respective authors for instance, Naddor (1966), Hollier and Vrat (1978), Winston (1994), Hillier and Lieberman (1995), Taha (1997), Silver *et al.* (1998), Zipkin (2000), Bloomberg *et al.* (2002), Baudin (2004), Carter and Evans (2006), Jacobs *et al.* (2011), Panneerselvam (2012) discussed many inventory models regarding inventory management.

1.3 Inventory management

Inventory management is the designing and managing of inventories for fulfilling the major characteristics of the organization. Inventory management needs information about expected demands, numbers of order for products stored. It also measured the scheduling and number of the reorder products. It is also stated that inventory management deals with keeping optimum investment in inventory and utilizing effective control system for minimizing total inventory cost. Inventory management helps business sector to control multiple inventories. It not only obtain reliable forecast of demand but also manage the physical and financial levels of goods holding, service-level given to customers.

Here are some purposes of inventory management such as:

(a) To reduce the probability of interruption during the manufacturing process.

(b) To describe and utilize better process for gathering, processing, communicating inventory data.

(c) To manage sufficient stocks of raw material, essential components during the period of urgent supply and predict price changes.

After that, following section is discussing about the importance of inventory management:

(i) It facilitates customers by allowing them with the items when they required. If inventory management level is not such good, then the availability of required items will be lower and delivery/shipping time will also be greater. To achieve smoother customer service-level, inventories must be managed which can be done by inventory management very well.

(ii) Sometimes inventories are holds in warehouse due to long-period, which results the goods may be spoiled (for example, fashionable goods, vegetables). Therefore, this problem can be a big financial issue for any business organization. If the organization uses a good/proper inventory management, then the entire inventory costs may be reduced.

(iii) Whenever inventories are stored in distinguished locations, it may be difficult to manage those inventories with customers demand. Hence, one justified inventory management system is very helpful to control those inventories with the service-level of customers demand.

(iv) Storage cost plays an important role for any manufacturing company's investment. Because, higher inventories needs more sufficient place which can directly effect to total cost. Therefore, company's profit may be lower. Inventory management allows companies to reduce the items which are stored in the warehouse. For this reason, storage cost cannot increases unnecessarily which results much profits for companies.

(v) Inventories are must managed by a proper way with the help of inventory management. As inventories are mismanaged, then a misconduct can happen between industry sector and customers. Then the growth as well as popularity of business organization can be decreases.

If poor investment takes place, then inventory faces shortage problems, disruption in production process, and selling segment. As a result, business organization may loose customers due to unsatisfied service-level. On the other hand, higher investment in inventory forms more cost of raw-materials which diminishes the profit. In spite of that inventories may be misused, deteriorated. Storage cost will be higher which results maximum inventory cost.

Some major factors regarding to inventory system are described in the following:

1.4 Demand

The number of units of a product needed by the consumer in a unit time is called as demand.

Different types of demand are discussed in the following division:

(a) Independent demand Completed/finished products which are sold to market, whose usage is configured on the basis of consumers demand in spite of another product's demand.

(b) Dependent demand Raw materials, small components, parts are utilized during manufacturing of other product. This will be clear by providing an illustration. One can consider a motor company which produces car. Now, a completed car can be regarded as a independent demand while tires, headlights are considered to be as dependent demand of that car.

(c) Time-dependent demand In earlier days, it is assumed that demand of products is constant all over the time. But, demand of products can vary with the fluctuation of time. For instance, whenever a new branded item reaches to market, it is seen that demand of that product reaches high level. After few months, demand may gradually increases or depletes with time. This concludes that demand is time-dependent. Harris (1913) considered an EOQ model with constant demand rate. After that, this model is described by Wilson (1934). Silver and Meal (1969) expanded earlier Economic Order Quantity (EOQ) models by varying demand. Later, Arcelus and Srinivasan (1985), Datta and Pal (1991), Koulamas (1993) discussed many inventory system with time dependent demand. By adding inflation with time varying demand, Hariga (1995) presented an inventory model. Zhou (2003) extended this work over multi-warehouse inventory model. Balkhi and Benkherouf (2004) arranged an inventory system along with stock, time varying demand, and deterioration of products. Teng *et al.* (2005) determined time-varying demand of products over an EPQ model. Respective Researchers such as Dye *et al.* (2006), Alamri and Balkhi (2007), Jiafu *et al.* (2008), Sakaguchi (2009) developed many inventory models related to time varying demand. Dye (2012) performed a trade-credit financing inventory model with time-dependent demand. Omar and Sarker (2015) made a Just-In-Time (JIT) integrated manufacturing model for time-varying demand. Further, Sarkar and Saren (2016) expanded earlier research works by incorporating variable deterioration and some ordering-transfer technique.

(d) Price-dependent demand Demand and selling-price are related to each other. Whenever selling-price of any product is declined at downwards, then consumers are more affective to purchase that item. In other way, if pricing amount of any product become higher, then demand of that product decreases automatically. This fact provides a conclusion that demand of products can be considered as selling-price-dependent. Many inventors like Wee (1997), Polatoglu and Sahin (2000), Mondal *et al.* (2003) obtained distinct inventory models regarding price-dependent demand. Teng and Chang (2005) highlighted some topics like deterioration, price and stock-dependent demand in an EPQ model. Afterwards, You (2006), You and Hsieh (2007) deduced such price-dependent demand inventory models. Maiti *et al.* (2009) discovered an inventory system for advance payment technique, stochastic lead-time, and also selling price dependent demand. Respective Researchers as Banerjee and Sharma (2010), Lin and Wu (2013), Sarkar *et al.* (2014), Alfares and Ghaithan (2016) formulated various inventory models on several topics like partial backlogging, reliability, ramp-type time-dependent demand, quantity discounts, price-dependent demand.

1.5 Inventory costs

Inventory costs are measured throughout the time of production of items (setup cost, ordering cost, purchasing cost), before and after selling of that products (holding cost, shortage cost, inspection cost, warranty cost, transportation cost, carbon-emission cost).

Inventory costs are described in each separate section.

(i) Setup cost This cost is known as the cost for adjusting a whole production system and assemble all production batch-associated matters. Earlier, setup cost and ordering cost are considered to be as similar. But now a days, business organization usually measured both the costs separately. Each of those costs creates several impacts on the annual total cost of companies. Setup cost includes some costs which are (i) constructing particular instruments setups, (ii) formulating the required materials, and (iii) suitably carrying out the former stock of goods. Chakravarty and Goyal (1986) investigated an inventory model with multi-item and setup cost. Setup cost must reduced to decrease the total annual cost. This setup cost can be declined by applying a small capital investment. By following this concept, some researchers such as Freeland *et al.* (1990), Hong *et al.* (1996) produced various inventory models. Haase and Kimms (2000) presented an inventory model with sequence-dependent setup costs. Afterwards, Chuang *et al.* (2004), Anglani *et al.* (2005), Hou (2007), Allahverdi and Soroush (2008), Annadurai and Uthayakumar (2010), Sarkar and Majumder (2013), Sarkar and Moon (2014), Sarkar *et al.* (2014), Sarkar *et al.* (2015), Liu *et al.* (2016) discussed some production-inventory models with setup cost reduction.

(ii) Ordering cost This cost occurs while any business organization places an order to purchase items, which they needed from any supplier or any other sources. Ordering cost incurs transportation cost, placing an order, telephone charges, tracking the order. Mostly this cost depends on quantity of ordered items. For instance, if a company purchase large amount or bulk size of inventories then there is a probability to obtain some price break, discounts on ordered quantity and transportation cost. Ordering cost can be function of some other costs which are (a) clerical cost to execute the purchase order, (b) cost for leveling items and counting ordered inventories, and (c) charge for maintaining the system with tracking the order. In general, this cost is dependent on the ordering quantity, carrying cost. If a company orders larger size of inventories then they have to pay few ordering cost. This concludes higher carrying cost appears for storing these inventories. While a company orders very few items, then they have to bear shipping charge very high, but lower carrying cost. Foote *et al.* (1988) formulated some heuristic strategies on ordering cost and lead time as randomly varied. Goyal (1990) presented an economic ordering technique throughout special discount duration. Matsuura and Tsubone (1993) produced a difference between centralized and decentralized control model with ordering cost. Lee (1995) proposed a continuous review stochastic inventory model by introducing delays in ordering cost. Ishii and Imori (1996) surveyed a production ordering model with assumption of two-product, two-phase, and capacity-constraint. Regarding ordering policy, several Researchers like Gallego and Scheller-Wolf (2000), Skouri and Papachristos (2002), Chun (2003), Mukhopadhyay *et al.* (2004), Chung *et al.* (2005). Chang *et* *al.* (2006) carried out some integrated vendor-buyer systems for ordering cost with controllable lead time. Ordering cost may not be fixed. With this concept, Hill (2007) produced an inventory system with fixed lead time and poisson demand. In this direction of research, Giri and Dohi (2009) constructed some inventory systems with some cost-effective ordering policies. Huang *et al.* (2010), Lin *et al.* (2012) formed an integrated inventory model with ordering cost, trade-credit policy, and imperfect items. As higher ordering cost results much annual total cost, to reduce ordering cost, Lou and Wang (2013), and Priyan and Uthayakumar (2014) discussed some integrated vendor-buyer inventory systems with highlighting some topics like transportation cost, backorder price-discount. Bijvank *et al.* (2015), Dai *et al.* (2016) made few inventory systems with ordering cost, lost sales, bounded shortage.

(iii) Purchasing cost The actual price paid for purchasing of items is called purchasing cost or unit cost. This cost is dependent on quantity which a firm purchased. Like carrying and ordering charges, this cost also effects the annual total cost. Hence, it is essential for any manufacturing company, firm to reduce the purchasing cost. Generally, large size of purchased items can help those companies and firm to diminish purchasing cost. Hwang *et al.* (1990) obtained an inventory model that allows quantity discounts with freight costs. Dong *et al.* (2001) presented a JIT system for buyer and supplier's purchasing analysis. Quayle (2002), Gao and Tang (2003) developed different EOQ models, in which several criteria on purchasing cost are assumed. The fact that purchasing cost remains same, it is not always true. Sometimes purchasing cost fluctuating with time. Generally, most of companies provides some discount policy on purchasing cost to draw an attention of customers for buying more items. With this information, Gavirneni (2004) made an inventory control system with optimal ordering policy by which one can obtained conditions under which optimal levels are ordered. Quintens *et al.* (2006) provided an idea about global purchasing policy. Berling (2008) generated a single-item inventory model in which setup cost is fixed and stochastic purchasing price. Dye and Hsieh (2010) presented an inventory model for fluctuating demand. In this way of research, for optimizing total purchasing cost several Researchers such as Rezaei and Salimi (2012), Sarkar *et al.* (2013), Park and Seo (2013), Dewi *et al.* (2015) assumed distinct inventory models.

(iv) Holding or carrying cost This cost occurs when inventories are stored in some warehouses for a unit period of time. Different types of inventories are usually hold in warehouse such as raw materials, defective products for repairing process. Finished goods or one can say (completed items) are also maintained in warehouse until its going to transport into distinct distribution center. Holding cost is a function of unit material price and a fraction of carrying cost which can be defined as a percentage of unit price/unit time. This cost incorporates some characteristics like holding facilities, handling, breakage, rent of warehouse, insurance, and taxes of capital. If holding or carrying charge becomes high, then company has to face large amount of total inventory cost. Whenever holding costs reaches higher, inventory levels becomes low and vice-versa. In general, holding cost varies from one company to another company. It depends on company's storage capacity, probability of deteriorated inventory. This would be clear by considering an example. Likewise, if a company has very lower capacity of stock holding i.e., the storage space is limited. In that case, company has to face higher holding cost.

Now, carrying or stock holding cost of inventory is defined as sum of each costs which are as follows:

(i) Storage place took by the inventory involves rent of place, electricity charge, insurance, taxes.

(ii) Money which needed to manage the inventory like cost of capital.

(iii) Cost for deterioration and obsolescence, usually, costs are calculated for a year and then described as a percentage of cost of the inventory items.

(iv) Maintaining and handling cost of inventories which are stored in warehouse.

(v) Charge are considered for labor cost during production of products.

Taksar (1984) considered stock-holding cost as discrete. Ching-Jong (1993) obtained a trade-off strategy between holding cost and setup time. Goh (1994) made many EOQ models by assuming general demand and carrying cost. By taking holding cost as non-linear, Giri and Chaudhuri (1998) determined some perishable inventory systems with stock varying demand. Teunter *et al.* (2000) described the policy, where holding cost rates are adjusted with reverse logistics system in an inventory model. After that, Bollen *et al.* (2004) developed some inventory systems with the facilities of holding items. Holding cost may vary from one company to another one due to their storage space facilities. For this, holding cost can be considered as variable. Some research are done under this consideration like Alfares (2007), Lee and Yoon (2010), Wagner (2011). Shah *et al.* (2013) surveyed an optimizing inventory as well as marketing policy with non-instantaneous, generalized types of deteriorating items, and holding cost. Additionally, holding cost may vary with available stock items in some warehouses, display areas. Therefore, holding cost is stock-dependent. Yang (2014) deduced an inventory model by introducing rate of both demand and holding cost as stock-dependent. Schlosser (2015) proposed an optimal pricing and advertising policy of some perishable items along with holding cost. In above section, it is found that all inventory holding costs are taken to be as fixed, variable, stock-dependent. In general, companies measured the time for how long they store items in warehouse during calculating holding cost. Hence, it can be found that this cost varies with time. Using this concept, Alfares and Ghaithan (2016) prepared a joint inventory and pricing model that provided quantity discounts technique with time dependent holding cost.

(v) Shortage cost This cost occurs while any organization has lots of demand but lack of products. When there arises shortage of goods in a firm, then customer either wait for ordered items or they may cancel their order. For this fact, it can be concluded that two types of backlogging case may arise.

(i) **Fully backoredered** If the unfulfilled demand is satisfied at a later date, i.e., after shortage customers wait for the ordered items. Then, this case is called fully backordered.

(ii) **Partially backordered** During shortage, if some of customers wait for the products but other moves to another company to get their products. Then this case is called partially backordered. Because in this case a fraction of unfulfilled demand is satisfied at a later date.

Shortage cost is summation of such costs as (i) loss of goodwill, (ii) lost of sales, (iii) loss of a customer, and (iv) loss of profits. Shortage cost generally depends on delay time, shortage quantity. It is difficult to calculate this cost as it may not be possible to figure out lost profits, effects of lost customers. Sometimes shortage cost has to guess based on random behaviour of demand during lead time. As a result, the assumed shortage cost is lower more than a guess. Although it is possible to measure a range of this cost. Deb and Chaudhuri (1987) first discovered shortage in an inventory model that allows demand as linearly time-varying demand. By highlighting shortages, Hariga (1995) obtained an inventory model with inflation, time varying demand, and time-value for money. Benkherouf (1998) designed a lot-size inventory system for deteriorating products with shortages. By assuming shortages as partial backlogging and deterioration of products, Wang (2002) formed an inventory replenishment policy. Papachristos and Skouri (2003) studied an inventory model where demand is taken to be as convex decreasing with respect to selling-price. Many inventors like Dye *et al.* (2006), Yang *et al.* (2010), Sarkar *et al.* (2012), Sarkar *et al.* (2013), Bhunia *et al.*

(2014), Jaggi *et al.* (2015), Ghiami and Beullens (2016) presented distinct inventory models by including some topics such as shortage cost, time-dependent demand, stock-dependent consumption rate, time-dependent deterioration, stock-dependent demand, delay-in-payments technique under inflation.

(vi) Inspection cost and inspection errors This section provides an idea to reader about the inspection cost and inspection errors. For imperfect production, there may arise few defective items as well as perfect products. This types of production can generally seen in long-run manufacturing process. Hence, each factories is to execute an inspection procedure by which they can identify defective products. After the inspection process, factories keeps those defective products for further reworking procedure. After the reworking procedure, defective products becomes perfect. If any production factory sells their finished products without checking those items then they are unable to determine which items are defective and which products are not. As results, they sell perfect items along with defective products to market. Because of this fault, companies can missed their consumers. Thus, there may arise some collapse in the factory. Generally, inspection process is considered during receiving the order from outside suppliers and after finishing the completing lots. Product inspection process generally takes place after the production system. Once the production process is finished, then product inspection policy is executed. This type of inspection segment also helps factories to reduce inspection cost. Because, if whole process inspection is performed then inspection cost will be high. Thus, annual total cost will also increased. Therefore, to reduce that cost, factories is to utilize product inspection policy. Considering inspection cost, researchers like Wang and Sheu (2001), Estes *et al.* (2004), Wang (2005), Ben-Daya *et al.* (2006), Ben-Daya and Noman (2008), Wang and Meng (2009), Bendavid and Herer (2009), Yoo *et al.* (2009), Nenes *et al.* (2010), Yoo *et al.* (2012), Chung (2013), Baudet *et al.* (2013), Bjarnason *et al.* (2014), Sarkar *et* *al.* (2015), Mohammadi *et al.* (2015), Rezaei (2016), Sarkar and Saren (2016) discussed about the impact of inspection cost.

During inspection, process examiner may falsely make some errors. For example, at the time of inspection he/she might has accepted those items, which are exactly defective goods. On the other hand, he/she may reject perfect items during inspection. This type of errors are called inspection errors. Mainly two types of errors can occur during inspection, which are (a) **Type I error** (whenever a perfect product is considered to be imperfect) and (b) **Type II error** (while a imperfect product is chosen to be as a perfect one). Usually, cost of incorrectly adoption of imperfect items is always maximum than the cost of incorrectly rejection of perfect products (for example, any imperfect food products, because its may harm consumer's life). Following research models are constructed with the assumption of inspection errors in any inspection policy. Bennett *et al.* (1974), Kittler and Pau (1980), Shor and Raz (1988), Rentoul *et al.* (1994), Ben-Daya and Rahim (1999), Wang and Sheu (2001), Ben-Daya *et al.* (2003), Wang (2007), Yu *et al.* (2009), Wang *et al.* (2010), Chen and Chang (2010), Khan *et al.* (2011), Lin *et al.* (2011), Hsu and Hsu (2013), Khan *et al.* (2014), Sarkar and Saren (2016) produced such inventory models.

(vii) Warranty cost This cost associated with the post sale cost. By observing the present market situation, it can be seen that retailer provides a time-period to consumers along with selling some products. This type of time-period is usually called as warranty period. For example, electronic goods like mobile phones are available into the market with the facility of one year warranty period. Within this period, if the selling item damages or failed to work. Then retailer replaced that product with another one or can changed the defective parts of that item. Warranty cost deals with some costs like (i) labor cost, (ii) repairing cost or replacement cost, and (iii) post sale cost. Several Researchers such as Blischke and Murthy (1992), Djamaludin *et al.* (1994), Chun and Tang

(1995), Monga and Zuo (1998), Yeh *et al.* (2000), Wang (2004), Murthy *et al.* (2004), Yeh and Chen (2006), Chen and Lo (2006), Giri and Dohi (2007), Liu *et al.* (2007), Wu *et al.* (2009), Chung (2011), Darghouth *et al.* (2012), Aggrawal *et al.* (2014), Sarkar and Saren (2016) developed so many research models with highlighting warranty cost.

(viii) Transportation cost Transportation cost arises mainly during the time of shipment of ordered items from one company to another or at the time of distributing finished items to several distribution centers. Transportation cost is also responsible to raise the annual total cost. Therefore, the impact of this cost cannot be disregarded. This cost may be fixed or sometimes variable. This cost depends on some factors, they are (a) length of the delivery route, (b) capacity of the delivery vehicle, (c) cost of fuel, diesel, petrol, and (d) uncertainty disruption during shipment. Gregor *et al.* (1982), Blumenfeld *et al.* (1985), Erenguc and Tufekci (1988), Ahn *et al.* (1994), Carter and Ferrin (1996), Das and Tyagi (1997), Melkote and Daskin (2001), Goyal (2007), Li *et al.* (2008), Lee and Jeong (2009), Leung *et al.* (2013), Priyan and Uthayakumar (2014), Shu *et al.* (2015), Hwang and Kang (2016) determined many vendor-buyer inventory models by describing transportation cost.

(ix) Carbon emission cost This cost occurs during the transporting of products through some delivery vehicle. Carbon emission is one of the main cause for global warming. Thus, it is necessary to reduce carbon-emission for production factories. Besides, at the time of manufacturing performance, production manager is to obtain low carbon scheme. After that scheme, production manager is to execute the application of low carbon production strategies. As transportation cost, this cost may also be fixed as well as variable. Various Researchers like Murthy *et al.* (1997), Reynolds and Broderick (2000), Jiusto (2006), Li and Hewitt (2008), Sadegheih (2010), Sarkar *et al.* (2015), Wang *et al.* (2016), Wang *et al.* (2016) observed several production-inventory model by adding carbon-emission cost.

1.6 Production

During production, if any failure occurs in the manufacturing machine i.e., any parts of that machine becomes useless. Then, there occurs some disruption in manufacturing system, which results no production in the company. For this ground, companies loose their regular customers as they are unable to fulfill requirements. It may directly effect the profit of that company. It is also seen that due to some machine breakdown, production becomes imperfect. Production rate is gradually decreases and the quality level of new produced items are low. Defective products can occurs during imperfect production. At the time of long-run production, defective products are generally occurs. In general, production process is done at separate departments in any companies/firm which are as follows:

(i) During production of a large item by using some raw materials. For instance, manufacturing of a car by utilizing tires.

(ii) Sometimes, reproduction process is done for bad handling of products by labors who works in the companies.

(iii) At the time of reworking procedure, production process is done to re-construct defective items as a original one.

After production process, defective items becomes perfect. Then that items are sold to the market. Liu and Yang (1996) obtained an inventory system for imperfect manufacturing system and rework. Salameh and Jaber (2000) extended previous research models into an Economic Production Quantity (EPQ) model. By providing shortages, an imperfect production process is proposed by Chung and Hou (2003). In this direction of invention, Wan (2004) provided a free-repair warranty offer on an EMQ. Almost all of above research works presented imperfect production system without any maintenance process. Lee (2005) introduced a model of inventory, where preventive maintenance is done into an imperfect production system. Many Researchers as for example, Chen and Lo (2006), Sana *et al.* (2007), Panda *et al.* (2008), Chung *et al.* (2009), Sana (2010), Sarkar and Moon (2011), Ouyang and Chang (2013), Pal *et al.* (2014), Paul *et al.* (2015), Nourelfath *et al.* (2016) optimized several inventory models with imperfect production system by allowing shortages, maintenance, delay-in-payments policy, reworking process, inflation.

1.7 Trade-credit policy

In earlier days, there was a common fact that while retailer purchase any products from supplier, then the retailer paid purchasing amount at the same moment. Retailer could not delay their payments. For this ground, suppliers also failed to earn any interest on the same purchasing amount from retailers. In present market scenario, it can be observed that supplier offers some time-period to retailer for adjusting their payment. This time duration is called trade-credit period. Within the circle of that time-period, retailers did not pay any interest to suppliers. But, if retailers are unable to adjust their payments within that fixed time-period, then they have to pay some interest to suppliers. For receiving this interest, supplier can increase their profit levels. In general, supplier used to provide retailers a full trade-credit technique. On the other hand, retailers used a partial trade-credit policy to customers. Retailers are also able to receive interest if their customers cannot settle the purchasing amount. Due to that reason, retailer can hold their paying amount until the last minute of credit-period. In this way, they can receive more profits. At first, Goyal (1985) formulated an EOQ model for delay-in-payments. Later, by considering trade-credit policy, there are many research models were formulated by lots of Researchers such as Kim *et al.* (1995), Aggarwal and Jaggi (1995), Khouja and Mehrez (1996), Liao *et al.* (2000), Abad and Jaggi (2003), Yang and Wee (2006), Tsao and Sheen (2007), Ouyang *et al.* (2008), Khanra *et al.* (2013), Chen *et al.* (2014), Sarkar *et al.* (2015), Sarkar and Saren (2015).

1.8 Time horizon

Time horizon is regarded as the time throughout which total inventory will be managed. Now, time horizon may be finite or infinite on the basis of the nature of demand. Sometimes, time horizon depends on the inventory system. By assuming finite or infinite horizon, several investigators like Balkhi (2001), Dey *et al.* (2006), Dey *et al.* (2008), Yu *et al.* (2011), Dye (2012), Gilding (2014) derived various inventory models.

1.9 Price-discount

Basically, business companies provides some price-discount to consumers if they purchase bulk size of inventories. This would help companies to receive more demand of products. Additionally, for selling large amount of inventories, those companies can reduce holding cost of stocks. On the other hand, companies may receive more profits by allowing those types of price-discount policy. By mentioning price-discount policy, lots of Researchers like Ardalan (1994), Dave *et al.* (1996) investigated many inventory models with price-discount policy. Similar research works over EOQ models are done by Fazel *et al.* (1998) and Viswanathan and Wang (2003). In this way of research, by highlighting some important elements like variable lead-time, resource constraints, delays in payments, stochastic demand, defective items, controllable lead time many investigators as Chang *et al.* (2006), Sana and Chaudhuri (2008), Lin (2009), Chang *et al.* (2011), Paul *et al.* (2014), Sarkar *et al.* (2015), Li *et al.* (2016) obtained many joint price and order quantity optimization models.

1.10 Deterioration

Deterioration is considered as evaporation and loss of utility of any product which turns that item into a useless one. Likewise, it is regarded by the damages, when products are broken or loose their marginal value for stress, bad handling. In real life situation, some items as fruits, vegetables, and fashion clothes are difficult to maintain. Because, these types of products are deteriorated with time factor. Therefore, the quality of such products are decreases automatically. Hence, these items are not in a good condition to sell in the market. Due to that reason, companies are unable to satisfy customers demand. Thus, the impact of deterioration cannot be neglected in production factories. Ghare and Schrader (1963) established an inventory model for exponentially deteriorating products. Various Researchers like Hariga (1995), Liao *et al.* (2000), Chung and Tsa (2001), Ben-Daya (2002), Goyal and Giri (2003), Khanra and Chaudhuri (2003), Wang (2004), Ouyang *et al.* (2006) produced several inventory models with deteriorating items as well as providing time-dependent demand, shortages. Sarkar (2012b) presented an inventory model by highlighting time varying deterioration and delay-in-payments. Sarkar and Sarkar (2013b) made an improved inventory system in which shortage is considered as partial backlogging, deterioration as time-dependent, and demand as stock-dependent. Deterioration of products cannot be constant. It may change with time to time. Therefore, it can be treated as time-dependent. With this assumption, Sarkar and Sarkar (2013a) developed an inventory system with variable deterioration and demand. Zhang *et al.* (2015) described a non-instantaneous deterioration inventory levels for stock-dependent demand. Wu *et al.* (2016) extended previous models by including time varying deterioration and trapezoidal-type demand rate.

1.11 Highlights of present research works

The following section of this thesis describes a brief introduction on some production-inventory, ordering-inventory models.

Chapter 2. Variable demand in a warehouse model

This chapter presents an inventory system to develop ordering and transferring strategy. The concept of random deterioration is assumed in this chapter to make this model more acceptable. Several demand functions are added to obtain the optimum profit. The main objective is to increase retailer's average profit. Supplier transport products to retailer by applying a multi-delivery policy with similar lot-size. Few numerical examples with graphical presentations are described.

Chapter 3. Price-discount and delay-in-payments in an inventory model

The proposed study explained an EOQ model for deteriorated products. Price and time dependent demand are illustrated in this study. In this model, a retailer, who purchases some items, enjoys a fixed credit-period offers provided by their supplier. Retailer offers also a fixed credit-period to their consumers. This model extended the model of Sana and Chaudhuri (2008) model [Sana, S., and Chaudhuri, K.S. (2008). A deterministic EOQ model with delays in payments and price-discounts offers. European Journal of Operational Research, 184, 509-533.] with price and time varying demand for finite replenishment rate. The associated profit function of retailer is maximized analytically. Finally numerical example and some graphical presentations are illustrated very clearly.

Chapter 4. Deterioration of fixed lifetime products in an inventory model

In this chapter, trade-credit policy for supplier and retailer are analyzed by extending Mahata's (2012) model [Mahata, G.C. (2012). An EPQ-based inventory model for exponentially deteriorating items under retailer partial trade-credit policy in supply chain. *Expert Systems with Applications*, 39(3), 3537-3550.] for deterioration of fixed lifetime products where Mahata (2012) mentioned exponential deterioration, but he assumed only constant deteriorated items. Numerical analysis with some graphical illustrations are depicted in this model.

Chapter 5. Trade-credit in an economic production quantity model

This chapter deals with the situation that supplier provided their retailer some full trade-credit technique. On the other situation, retailer also allows consumers some partial trade-credit policy. Due to that ground, retailer can enhance their profit level. In this chapter, exponential deteriorating items are taken. This chapter is presented for minimizing retailer's annual total cost. There are some graphical illustrations for several conditions and analytical formulation of this model. There are few numerical examples for distinct conditions in this chapter.

Chapter 6. Inspection errors for an imperfect production system

At the time of manufacturing of items, all produced items are considered as perfect in general. Imperfect products may occur throuout deteriorating production procedure. Product inspection policy is assumed in this chapter to reduce inspection costs and total cost. In this chapter, Type I errors, Type II errors, and warranty policy are highlighted.

Chapter 7. An integrated-inventory model with environmental issue

This chapter introduces the concept of carbon-emission cost during single-setup-multi-delivery (SSMD) policy. Some investment function is added to reduce the setup cost. Delivery lot-size during each shipment is taken to be as unequal as well as variable. After getting the delivery items, buyer sent back all imperfect products for reworking process. Hence, end consumers will receive only perfect products. The main aim of this model is to reduce vendor and buyer's joint total cost. An analytical derivation is designed to obtain optimality of this model.

Chapter 8. Integrated-inventory model with stackelberg game

This chapter highlights an integrated inventory model which incorporated Stackelberg game policy. Carbon emission is discussed, which makes this model more acceptable in the real life situation. This study develops about setup cost reduction. The proposed is constructed to increase the total profit over finite planning horizon. A numerical analysis is applied to clarify this model.